National Aeronautics and Space Administration

The Need for Intelligent Control of Space Power Systems

Ryan D. May

Vantage Partners, LLC

James F. Soeder, Ray Beach, Nancy McNelis

NASA Glenn Research Center

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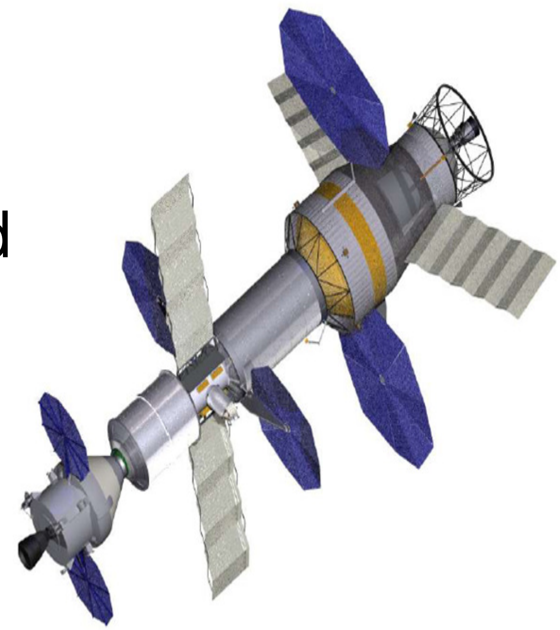
Overview

- Spacecraft Electric Power Systems
- Why the need for autonomous control?
- EPS Control Objectives
- What is intelligent power control?
- Long-Term Vision
- How do we get there?

Space Power Systems

- Multiple solar arrays
- Lithium Ion batteries
- Spacecraft may be docked/undocked
- Spacecraft may be manned or unmanned



- Power is the most critical system on board
  - ≈ 100% availability
  - Highly redundant, fail-safe
  - Must be robust to unforeseeable failures!

Why Autonomous Control?

- Present power systems rely on continuous support from mission control

- As spacecraft move away from Earth new issues arise:

Mission	Duration of Mission After Incident	Communication Latency Time
Deep Space Habitat	9 months to 1 year	15 to 45 mins.
Apollo/Orion	3 – 5 days	1 to 2 sec.
Mount Everest	1 – 2 days	Real time
Deep Sea Submersible	8 hours	Real time
Shuttle	2 – 5 hours	Real time
Submarine	1 – 2 hours	Real time

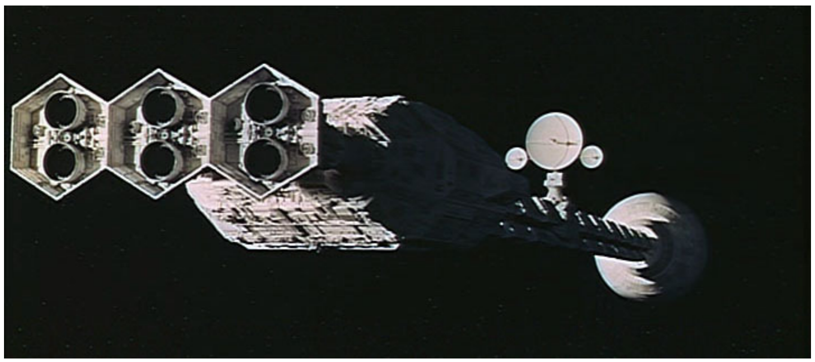
EPS Control Objectives

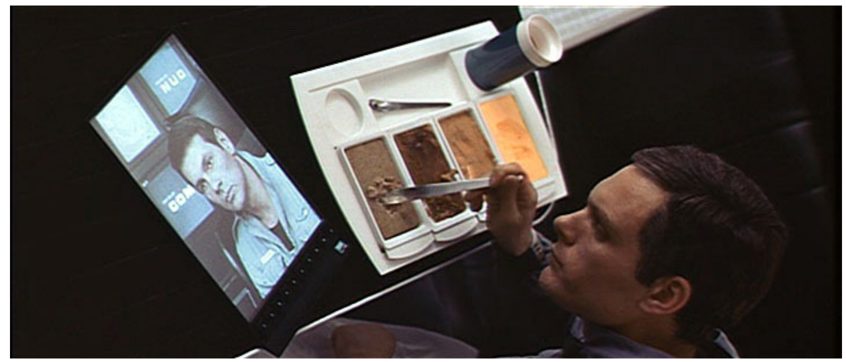
- Energy Management
  - Generate enough power to meet all demands on the system
  - Distribute that power in the most efficient manner
  - Generate that power using the most efficient generators
  - Distribute power such that all line constraints are observed
- Load Management
  - Enable load prioritization so that critical loads will be met during outages
- Network Security
  - Ensure that unanticipated component outages will not destabilize the system

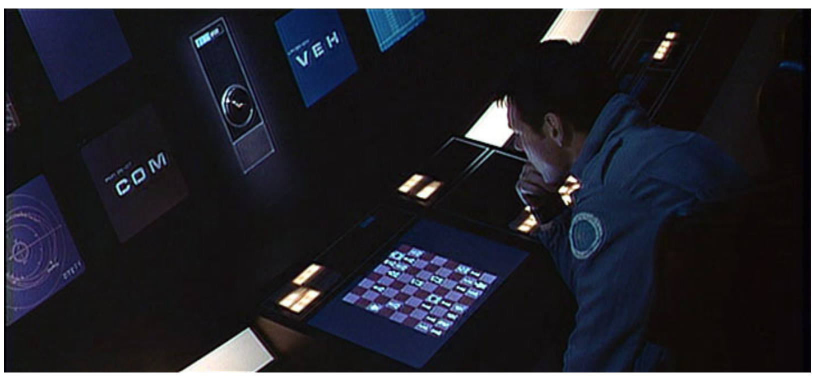
Intelligent Power Control

- There are a very large number of possible failure modes
  - Infeasible to prepare a “scripted” solution to every possible scenario
  - During failures, some of the control objectives may be in direct conflict
- As the mission progresses, the priorities of the power system will change
- “Intelligent” control:
  - The ability to adapt to an arbitrary system configuration and maximize system performance given time-varying constraints and goals

The Vision







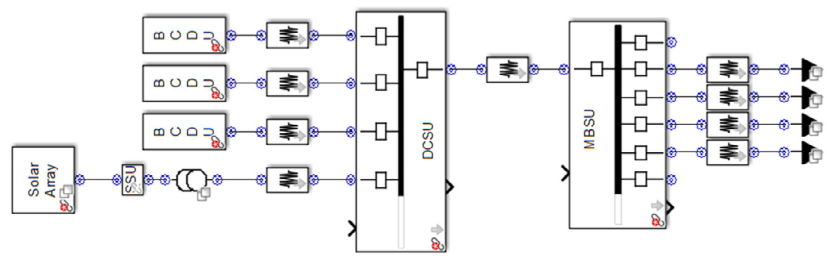
In the 1960’s, the operational vision for a spacecraft was routine and mundane for the astronauts – autonomous operation of core systems

How do we get there?

- Define an architecture:
  - Centralized
    - More familiar and has a very successful legacy
    - Relatively easy to debug problems
    - Requires a near-perfect knowledge of the system state
    - Needs to have a robust sensor system to determine the location/impact of any failure
  - Distributed
    - Potentially more robust and flexible than centralized system
    - Less familiar to engineers
    - Diagnosing/debugging system problems can be very challenging
    - Adds a new communication system

Development & Validation

- Apply control strategies to a Simulink simulation of the International Space Station
- Control initially implemented in Simulink
- Migrate control to Rockwell Automation’s ControlLogix hardware
- Incorporate physical hardware into simulation
- Act as a “supervisor” at ISS Ground Control
- Move control onboard ISS, monitored by Ground Control



Conclusions

- As we move farther from Earth (manned and unmanned) the need for autonomous control increases
- Control needs to be intelligent as well as autonomous to enable the system to respond to unanticipated failures

- Evaluate different control strategies to determine which system to move forward with

- Long progression of testing and validation to build confidence in control system prior to giving it direct control

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